Low Temperature Research on the International Space Station

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Abstract. The Low Temperature Microgravity Physics Facility (LTMPF) is a state of the art facility for conducting fundamental research in a microgravity environment at low temperatures. The LTMPF is a self-contained, reusable, cryogenic facility that will be attached to the Exposed Facility of the Japanese Experiment Module, named Kibo, on the International Space Station (ISS). The first launch of the LTMPF is scheduled in June, 2004 and will carry one or more low temperature experiments. Currently, there are six candidate experiments competing for several flight opportunities from the fields of Low Temperature and Condensed Matter Physics, and Gravitational and Relativistic Physics. Science community input has been solicited in the design and development of the LTMPF. In order to create a facility that is useful to current and future experimenters, requirements generated by the current flight definition experiments were taken into consideration early in the design phase of the LTMPF. In addition, inputs from previous, existing and potential future science investigators, as well as industrial partners, were sought in order to design a facility that is modular, adaptable and upgradeable to meet the long-term needs of the science community.

INTRODUCTION

With the era of the International Space Station (ISS) just beginning, regularly scheduled space shuttle flights for large fundamental science payloads, such as the United States Microgravity Payload (USMP) missions, have ended. To continue progress in low temperature microgravity research, highlighted by the successful USMP experiments, the Lambda Point Experiment (LPE) launched in 1992[1], and the Confined Helium Experiment (CHeX) launched in 1997[2], an alternate platform for microgravity research is needed. In 1994, the National Research Council (NRC) Space Studies Board recommended that a low temperature facility be constructed for the ISS. Later in 1995, the Low Temperature Science Steering Group (LTSSG, now the Discipline Working Group, DWG), reiterated the same recommendations. A request for proposal to build a low temperature facility for the International Space Station was distributed to the aerospace industry in 1995 and Ball Aerospace and Technologies Corporation was selected to participate in the development of the LTMPF.

The LTMPF project is based at the Jet Propulsion Laboratory (JPL) and includes Principal Investigators (PIs) from the University of New Mexico, the University of California at Santa Barbara, Stanford University, and JPL, with co-Investigators located in France and Germany. The objectives of the LTMPF are to provide more frequent access to space, increased sensor capabilities allowing for more diverse science opportunities, and longer experiment operation time in the microgravity environment, as compared to the nominal two week experiment time available on the Space Shuttle. Much of the LTMPF concept is based upon the past experience of the two previous low temperature microgravity experiments flown on the USMP series of shuttle flights: LPE and CHeX. The PIs, at their home institutions, conduct ground-based low temperature fundamental physics research, define their flight experiments, and develop that part of their apparatus which is specific to their investigations. The PIs may also develop and prove new technologies necessary to perform their experiments in space. The low temperature facility includes a cryogenic dewar, electronics, mechanical and thermal support structures, and structures necessary to interface with the ISS and launch vehicles. JPL, in addition to providing overall project definition, management and implementation, is responsible for constructing the thermo-mechanical probe structure required to interface the experiment specific hardware to the cryogenic dewar contained in the LTMPF.

FLIGHT DEFINITION EXPERIMENTS

There are currently six candidate experiments competing for flight opportunities onboard the LTMPF. These investigations were chosen through the NASA Research Announcement (NRA) science selection process. The science focus of the selection process is guided by the *Fundamental Physics in Space Roadmap* which was prepared by a large team of scientists, technologists, and educators from the university community, industry, and government. The *Roadmap* identifies two long term fundamental goals of NASA's research program, called "Quests," and three focused sets of scientific investigations, known as "Campaigns." The two Quests for fundamental physics research are "to discover and explore fundamental physical laws governing matter, space, and time," and "to discover and understand organizing principles of nature from which structure and complexity emerge." In order to satisfy these two Quests, there are three Campaigns that define areas of study and focused investigation. These campaigns, which have significant scientific and technological overlap, are gravitational and relativistic physics, laser cooling and atomic physics, and low temperature and condensed matter physics.

The NRA science selection process for flight and ground based investigations occurs on an average of once every two years and the experiments are selected through peer review based on scientific merit and need for microgravity. The six current flight definition experiments include the Superfluid Universality Experiment (SUE), Critical Dynamics in Microgravity (DYNAMX), the Microgravity Scaling Theory Experiment (MISTE), Boundary Effects on the Superfluid Transition (BEST), Experiments Along Coexistence Near Tricriticality (EXACT), and the Superconducting Microwave Oscillator (SUMO). Many of these experiments are condensed matter experiments performed using liquid helium samples (^{3}He and ^{4}He) and make use of high precision, SQUID-based thermometry which was originally developed for LPE. The current candidate experiments have continued this sensor development and have made improvements on the inherited techniques. SUMO represents a class of experiments exploring gravitational and relativistic physics in a low temperature microgravity environment.

LTMPF REQUIREMENTS

Input from scientists currently working in fields which may benefit from access to a low temperature environment in microgravity was actively sought to design a facility useful for cutting edge science. A Science Requirements Envelope Document (SRED), finalized in September, 1999, was created to capture this input. Particular attention was given to the six current flight definition PIs, who are in the process of developing their own individual science requirements specific to their experiments. The goal of the SRED is to "envelope" the needs of each of the flight definition experiments, capturing the common needs of all the experiments while at the same time insuring that PI specific items were not excluded by an evolving conceptual design for the facility. Inputs from previous flight experiment PIs, participants of fundamental physics workshops, and fundamental physics ground PIs were also incorporated into the SRED.

In addition to the requirements generated by consideration of the needs of the science community, there are many other sources of constraints which affect the design of the LTMPF. Such sources include the ISS, the Space Shuttle, the JEM EF, and the H-IIA (Japanese launch vehicle). Requirements derived from operating in space environments, such as the survivability of electrical components in space, must also be considered in the development of the facility. These requirements, as well as those derived from the SRED, are combined into a Functional Requirements Document (FRD) which guides the future design of the LTMPF.

FACILITY DESCRIPTION

The Low Temperature Microgravity Physics Facility (Figure 1) is essentially a complete low temperature laboratory that is attached to the International Space Station on the Exposed Facility of the Japanese Experiment Module (named Kibo). From the constraints of the projected carriers and the docking location of the LTMPF, the physical size of the facility is constrained to a volume of 1.85mx1.0mx0.8m and a mass of 500 kg. The current project baseline is to build two identical facilities, each of which is capable of supporting two experiments. The key feature of each facility is a superfluid helium dewar with the capability to reach and maintain a base temperature of at least

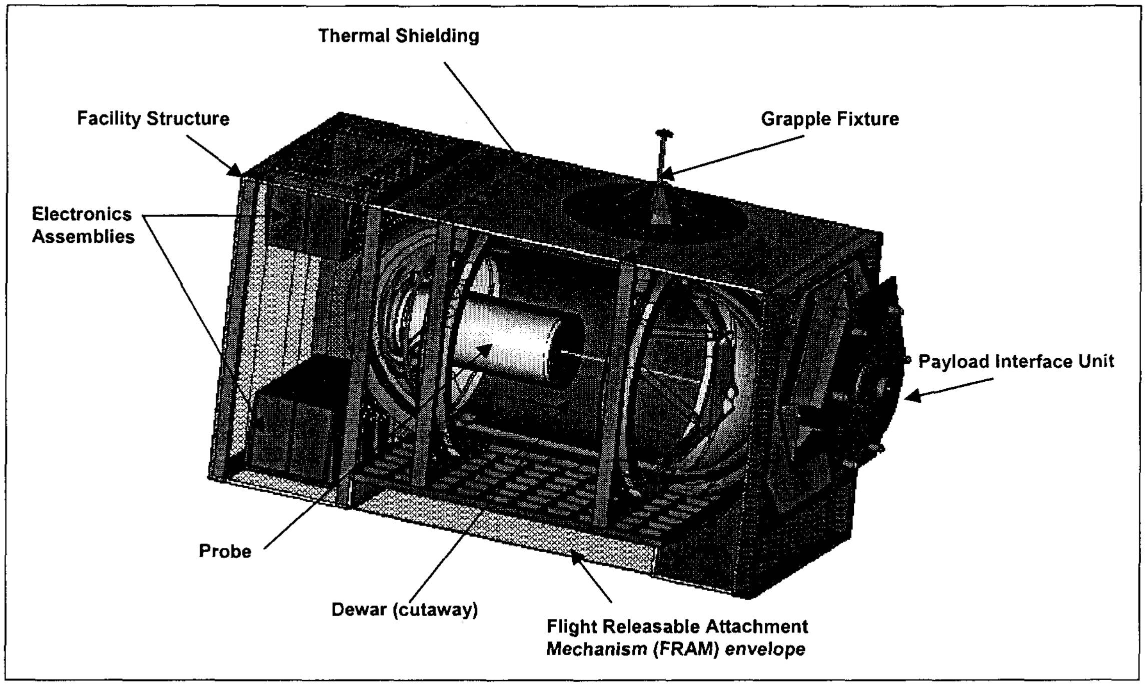

FIGURE 1. Conceptual Drawing of the LTMPF.

1.6 Kelvin for a period of 4.5 months. This dewar will house the scientific instrument consisting of the experiment specific hardware of the PIs, integrated into a highly stable thermo-mechanical platform.

To support the scientific instruments located inside the dewar, an extensive system of electronic and mechanical equipment, as well as thermal, electrical and magnetic shielding, and mechanical structures is located within the facility. Electronics being designed and built for the facility include Super-conducting Quantum Interference Devices (SQUIDs) used to make precision temperature and pressure measurements, resistance thermometry and precision heaters for thermal control and experiment operation, and other electronics specific to each individual experiment. The overall design of the facility electronics is modular and flexible to meet the needs of future experimenters. A modular system for handling gas supplies for experiment control and sample supply, as well as optical access capability to the instrument area is available. An onboard flight computer controls all facility and instrument electronics, command, telemetry, and data storage during on-orbit operations.

Most candidate experiments are sensitive to random vibrations, charged particles, and stray magnetic fields. The LTMPF is constructed with a passive vibration isolation system attenuating vibration levels coming from the ISS to below 500 μg rms at the instrument. Several layers of magnetic shielding are built into the instrument probe to protect the experiments from on-orbit variations in the magnetic field environment. The vibration and radiation levels will be monitored and real time data will be provided to experimenters. The facility is built with the mechanical and thermal structures necessary for survival in the environments encountered from launch and attachment to the ISS, through return and landing of the LTMPF on the Space Shuttle.

LIFECYCLE OF THE LTMPF

Once the facility and the two flight experiments are built and tested by their developers, the hardware is shipped to JPL for final integration and testing. After integration, the entire facility is shipped to the launch site cold. The facility is manifested for its first launch on board a Japanese H-IIA rocket in June, 2004 from the Tanegashima Space Center in Japan. Once on station, the experiments simultaneously take data for four and a half months. After cryogen depletion, the LTMPF may continue to monitor environments on board the ISS while it awaits return by the Space Shuttle.

While one of the facilities is docked on the ISS taking data, the next set of flight experiments are integrated into the second facility and tested. Subsequent launches of the facility will be by H-IIA rockets or by the Space Shuttle. However, the LTMPF can only be returned by the Shuttle. It is estimated that there will be a 1 to 2 year cycle time between flights of the facilities. On return to Earth, the experiments are deintegrated from the facility and may then undergo some post-flight testing at the PI home institution. The facility is refurbished for the next set of experiments and the new experiments are integrated for the next launch. Each facility is being designed to survive five cycles of testing, launch and landing, providing for up to twenty years of service and microgravity access to low temperature, fundamental physics investigations.

FACILITY STATUS

The LTMPF project has recently (9/9/99) completed a successful Requirements Definition Review (RDR) for the facility. A baseline design of the facility, project implementation, and science requirements were reviewed by separate non-advocate science and engineering panels. RDRs for the first three candidate experiments (MISTE, SUE, DYNAMX) will be conducted later this year and Science Concept Reviews (SCRs) for the next three experiments (BEST, EXACT, SUMO) will be held early next year. The facility will undergo a Preliminary Design Review (PDR) early in 2000, after which final design and flight build will commence.

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